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STUDY ON THE RELATIONSHIP BETWEEN CAPACITY, COST AND OPERATION ALTERNATIVES OF BUS RAPID TRANSIT

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Abstract: In this paper, the authors aim to develop transit capacity estimation model based on observed data in Japan and Brazil and to evaluate the capacity of BRT with the model, focusing on the possibility of the improvement in transit capability of BRT, considering the possibility to apply the output to the cases in Eastern Asia region. Based on these conditions, the authors developed the transit capacity estimation model with several variables, including structure of bus stop, fare collection system, bus stop interval, employment cost and so on, and evaluated the transit capacity of BRT with exclusive busway. In conclusion improvement of bus operation system such as bus stop or operation system could enhance the capacity and level of service of bus transit system up to that of rail based linehaul transit system, with maintaining present operating cost level.

Key Words: Bus Rapid Transit, Transport System, Urban Transportation

1. INTRODUCTION

In metropolitans in Asia, it is suggested that there should be the need to implement bus-based linehaul transit system with exclusive busway, which is referred as Bus Rapid Transit (BRT) in the United States recently. Actually, in the Eastern Asian regions, the exclusive busway systems have been introduced in Seoul (Korea), Taipei (Taiwan) and Jakarta (Indonesia) in these few years and planned in Manila (Philippine) and Kunming (China).

It is generally believed that the capacity of bus transit with exclusive busway is lower than that of rail based linehaul transit system although the system is less expensive. However, GAO (2001) show that improvement of bus operation system could enhance the capacity of bus transit system with exclusive busway up to that of rail based linehaul transit system. Moreover, the capacity of bus transit system is the function of several factors including vehicle type, design of bus station, fare collection system, signal priority system on exclusive busway, bus stop interval and bus operation. Furthermore, there are some variations on respective factors. Therefore, it is required to evaluate how these factors affect on the capacity of bus transit system in developing countries.

Recently, Bus Rapid Transit (BRT) that was improvement of the bus system with bus lane and/or exclusive busway has been included in national transit strategy especially in United States and Canada, and it has also become feasible because of the less cost than that of the rail based linehaul transit systems. (cf. TRB, 2003) It is significant to consider the feasibility of BRT as alternatives for rail based linehaul transit system in Asian cities, which cannot introduce them due to financial reasons in spite of implementation needs. Recently, research reports including the characteristics of BRT and manuals including descriptions such as the requirements of decision making process have been published, and performance evaluation regarding BRT has been applied in several countries all over the world.

Meanwhile, when the authors introduce BRT for Asian cities, it is not necessarily the best way to apply these manuals to those cities directly, because the preconditions of calculation and the speed of urban growth differ considerably among countries. Therefore, the concept of BRT should be applied with due consideration for the preconditions in Asian cities.

In this paper, the authors aim to follow three points with focusing on the role of BRT as the public transit system. Firstly, the authors estimate the capacity of BRT under operational characteristics in Japan and Brazil. Secondly, the authors compare the cost required in order to achieve the capacity of transit alternatives. Finally, the authors examine the requirements which should be taken into consideration to apply BRT in Asian cities.

2. REVIEWED STUDIES AND ISSUES OF BRT

2.1 History of BRT

The bus transit system with exclusive right-of-way for bus is less of new measure. The authors classify Historical and Current Situations of the Exclusive Busway in chronological order as below.

The first Exclusive Bus lane on a city street was initiated in Chicago in 1939. The transportation plan suggested in 1937 called for converting three rail transit lines to express bus operation on highways with on-street distribution in central areas and downtown. Subsequently, this type of development was implemented in several other cities in the United States. However the concept was not high quality service such as BRT but replacing streetcar service with simple bus operation.

In the 1960s, a transit mall with reserved bus lane has been implemented in several cities. A transit mall is a set of designated and reserved lanes on surface streets, usually as a component of downtown improvements. The first implementation was the Nicollet Mall in Minneapolis (1967), followed soon in Chicago, Philadelphia, and Portland. In the 1970s, a discontinued streetcar line was converted a reserved bus lane with the aim of preserving it as a public transportation axis in Liege, Belgium.

A large step forward in the United States was the development of busways as components of limited-access highways within metropolitan areas, against the background of establishment of Urban Mass Transportation Act (1964) and positive investment to public transportation of funding sources for road. The first true busways in the United States were placed on the Shirley Highway (I-395), Washington, D.C. and on the San Bernardino Freeway (I-10) running due east from downtown Los Angels to El Monte. Planning for both of these facilities started in the late 1960s; the first opened in 1969, the second in 1973.

In the 1960s, the planning of the exclusive busway as bus priority system was introduced not only to the urban areas but to the new towns. The entire urban structure of Runcorn new town in Britain, authorized in 1964, is based in a central roadway that allows only buses to operate on it. There is a figure-eight loop that has a total length of 19km that is designed a 5-minute walking distance from residences to all significant destination point. And then, this concept has become the pioneer of following new towns.

In the United States of the 1970-80s, the development of HOV lane, for example operation was started in Seattle in 1971, was started in the concept of Transportation System

Management (TSM) and the utilization of public transportation was proposed as a short-term project in the concept of Travel Demand Management (TDM) corresponding to progress of motorization.

By 1974, Curitiba, Brazil, had opened bus transit system with exclusive busway that was a trailblazer of BRT at present. Curitiba's Bus system was developed in stages as an integral part of an overall master plan whose basic objectives included radial expansion of the city along five structural axes, integrating land use and transport, and protecting the traditional city center.

In Ottawa (Canada), world class bus network was established during the 1970s with the passage of the Official Plan and strengthened in subsequent updates. Today, a grade-separated right-of-way reserved just for bus what called the Transitway has operated in stages with construction of the high-density and high-rise housing or shopping center of suburban district. Ottawa's bus routes travel along parts of the Transitway or connect at one of the stations. Many stations are located next to major shopping centers or employment centers.

In 1980, a guided bus that uses mechanical roller arms so-called O-Bahn was opened as a pilot project in the city of Essen in Germany. The concept contains an automatic track guidance for buses that is cost-effective, especially where elevated construction is required.
The concept enables a standard service bus to be steered both manually and automatically in t
rack-guided operation. In the latter mode, guide rollers directly connected to the steering knuc
kle of the bus steer the bus when it moves along the tracks' lateral guide rails. In Adelaide, Au
stralia, 12km O-Bahn Guided Busway that links downtown Adelaide with the northeastern su
burbs opened in 1986 and was completed in 1989. Moreover, in several cities, Leeds, Ipswich,
and Bradford in United Kingdom, short section of guided busway have implemented in order
to bypass a cross section as bottleneck.

In the end of 1990s, Bus Rapid Transit (BRT) that was improvement of the bus system throug
h the use of bus lane and/or exclusive busway was considered strategically with reference to t
he case example of South American cities, and it has also become feasible because of the less
cost than that of rail based linehaul transit systems. Recently, the advantage of bus transit syst
em has been reappraised as could be observed in the operation cases such as in Nagoya, Taipe
i Seoul and Jakarta, and the planning case in Manila and Kunming.

2.2 Review Studies of BRT

FTA (2004) defined BRT as: A flexible, high performance rapid transit mode that combines a variety of physical, operating and system elements into a permanently integrated system with a quality image and unique identity. According to the report released by U.S. GAO (2001), BRT is predominance in respect of operating cost rather than LRT, as a result of data comparison of six cities that are operating both BRT and LRT. In the case of the capacity analysis of BRT with exclusive busway, there are examples in which actual operating data were used as well as examples of calculations that were made under hypothetical corridors.

Then, if the authors focus attention on cases of BRT other than U.S., there are many cases to be introduced BRT as the mass transit in addition to improvement in bus punctuality and reliability. For example, BRT in Curitiba, Brazil, was developed as an integral part of an overall master plan whose basic objectives included radial expansion of the city along five structural axes integrating land use and transport. Today, they achieve 14,000 passengers per hour per direction with tube-designed stations and 270-passenger bi-articulated buses operating on busways. However, the bus system draws on the concept of mass transit rather than rapid transit in respect that average speed of the operation on busway is about 20km/h due to short interval of stations (average 400m). (cf. Meirelles, 2000)

In Porto Alegre, Brazil, high-capacity bus convoy system was developed, and it evolved into Bus Ordering system in which buses are allocated to one of three groups (A-B-C). The buses arrive and are marshalled into the preferred sequence, though not into strict convoys. Bus ordering system is device for preventing confusion that passengers do not know which bus they should board at median stations. This system operates effectively and can improve commercial speeds at high levels of passenger demand (more than 30,000 passengers per hour per direction).

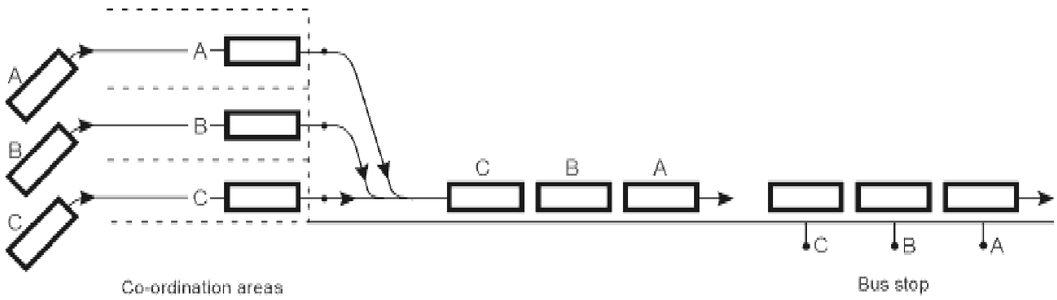


Figure 1. The Concept of Bus Ordering (Source: Meirelles, 2000)

As shown above, improvements of bus operation system could enhance the capacity of bus tra nsit system with exclusive busway up to that of rail based linehaul transit system. Therefore, it is important to evaluate the transit capacity under preconditions such as bus operation improv ements and infrastructures which can contribute to enhancement of punctuality and reliability.

2.3 Issues of BRT

The calculation of capacity of a bus transit system with exclusive right-of-ways should be evaluated from both theoretically and empirically aspects.

Factors that define the capacity of public transit can be broadly divided into four categories: (a) spatial constraints, (b) costs involved in operation, (c) institutional aspects such as legal constraints and (d) technical aspects such as methods of operation. For example, if space and cost were unlimited, by using various kinds of technology buses could achieve the equivalent capacity as transit systems with rail based linehaul transit systems such as railways. In that case, however, the same kind of large-scale station facilities and transfer terminals as railways would be needed and very greatly increased personal expenses would have to be considered due to the substantial increase in the crews required for the operation. Moreover, technical aspects would require planning in case spatial limitations should occur. The technology here would possibly involve vehicle technology for reducing the travel space required by buses and decreasing the dwell time at a station. Furthermore, technical innovations would be reflected in transport costs as generated expenses and relationships with the legal system would need to be considered.

In this paper, the authors propose a method of analysis that coordinates a microscopic approach focused on technical and engineering aspects and a macroscopic approach focused on the trade-off between various limitations as a means of clarifying the interrelationships between the various factors. The technical factors that define bus capacity include vehicle performance, vehicle operating methods and service control (including signal control and Bus Ordering). The authors evaluate capacity and travel speed per hour by microscopic simulation model called tiss-NET (traffic impact study system for road NETwork), which is the traffic simulation package which include vehicle behavior models. (cf. Sakamoto, 1999) The tiss-NET is designed for micro-level traffic phenomena and may have applicability to evaluate the alternatives of bus operation. On the other hand, for clarifying the interrelationships of factors other than the technical aspects that are involved in the evaluation of capacity, the authors evaluate their trade-offs on macroscopic aspect. For instance, when a certain demand for transportation has been presented, one can consider organizing the relationships between service levels and costs and the construction of the system that would be needed for the demand to be handled by bus transit, and the relationship between the conditions of cost and spatial limitations that would be needed for a linehaul transit system to achieve the same conditions.

Observations with respect to capacities and costs of various systems are made in Chapters 3 and 4 on the basis of results of calculations under simple preconditions. Carefully considered necessary conditions for applying BRT in various Asian cities are discussed in Chapter 5.

3. METHODS OF BUS OPERATION ON BUSWAY EVALUATION OF CAPACITY

In this chapter, having configured alternatives for bus stop operation on exclusive right-of-way based on the viewpoint of configured examples and analyses set out in the previous chapter, the authors calculate a simulation under simple preconditions. For evaluating the calculated results, the authors configure evaluation indicators related to capacity such as the relationship between bus capacity and average speed, and examine the capacities of bus transits that used an exclusive right-of-way.

3.1 Definitions of Transit Capacity

The capacity of a transit system can generally be defined as the maximum number of units (in the case of buses, the number of vehicles) that can pass an arbitrary point on a route in one hour under certain conditions. (cf. TRB, 2000) The service frequency, which is the number of vehicles that pass an arbitrary point on the route, is the reciprocal of the service spacing and the place with the shortest service spacing in each section of the route regulated the service frequency of the route. Generally, because the service spacing at stopping point (stations) for users to boarding and alighting is invariably larger than at an arbitrary point the route, the capacity of the transit system is controlled by the capacity of the station with the longest dwell time (the largest station that handles people boarding and alighting).

Normally, configuration of bus frequency take into account the acceleration and deceleration of the vehicle, station dwell time and delays at intersections that are controlled by signals. Moreover, for a bus transit in urban areas congested with other vehicles, in addition to the factors mentioned above, the effects of intersections continuously controlled by signals and on-street parking must be considered. However, to increase the speed and regularity of bus transit, other vehicles are physically segregated from the exclusive busway that is evaluated in this paper and in the case of an intersection with an local street, even if there is a grade separation or a level intersection with signals installed, in most cases in Japan the public transportation priority system (PTPS) provides buses with preferential right of way as a precondition. Consequently, the authors determine that bus transit capacity can be evaluated for a bus transit on exclusive right-of-way by taking account of dwell time at stations and waiting time at intersections controlled by signals.

Incidentally, with calculations that have been simplified, it can be argued that the dwell time at stations is an average value but the numbers of people boarding and alighting are not the same at all stations and there is a type of variation of dwell times at each station. For this reason, when the service frequency is high, this variation of dwell times may cause a queuing of buses to wait at a station and this becomes the cause of a so-called bus bunching. Therefore, in order to reproduce such conditions, it is useful to evaluate capacity with simulations model that take account of variance of dwell times and the presence or absence of prioritized signal control at intersections.

3.2 Preconditions

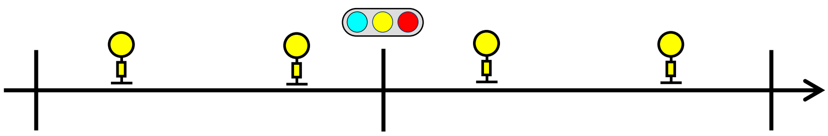
Here, several preconditions are identified before the authors apply a simulation model that takes account of what has been shown above.

With respect to the capacity analysis of exclusive busway, Zargari (1998) evaluated the capacity by use of actual operating data. Fernandez (2002) calculated the performance under hypothetical corridors. In Japan, there are no examples of BRT with exclusive busway according to the plan and it is difficult to obtain actual operating data. Therefore calculations in this research are made in the same process as the latter method under hypothetical conditions.

As shown in the previous section, exclusive busways targeted in this research are supposed to be under the following conditions such as that they are closed to other vehicles other than emergency vehicles, that the number of level intersections installation at local streets is minimized, that signal-controlled intersections with busway are not arranged in succession, and that PTPS is installed at the majority of intersections.

Here, as shown in Figure 2, a corridor (a 2km one-way single lane dedicated bus transit) with signal-controlled intersections is assumed that is to be evaluated by this analysis. Only buses can travel this section, which is closed to the entry of other vehicles. The maximum speed is set at 50km/h. Moreover, station interval is set at 500 m and buses stop at all stations. The average speed is evaluated only over the target section and the turn-around time at origin and destination points is excluded.

When we evaluate the capacity of busway, we must consider strictly the effect of seriate intersections on it. However the factors that affect the capacity are represented mainly by bus dwell time at stations and characteristics of intersections with or without priority signal control. Therefore, it is considered that the validity of setting preconditions for the simulation of this study is ensured.



Total Length:2km（Interval of Intersections:1km,　Interval of Bus Station0.5km）

Figure 2 Corridor for simulation

3.3 Alternatives of Bus Operation at Station

In the simulation, we focus on four systems that a normal bus operation (a bus stop at each station sequentially), an operation by the use of 25m long bi-articulated buses to carry 270 passengers, a system for setting up bus bays at each station that will enable several buses to stop at the same time to boarding and alighting, and Bus Ordering system under the control of signals. In this research, the authors classify some combinations of these and calculated in Table 3 as alternative proposed methods of operation to be used in analyses.

Table 3. Classification of Bus Operation Alternatives

Simulation Case		Passing Lane	Number of Bus Bay	Notes
1	Normal Operation	No	1	
2	High Capacity Operation （bi-articulated bus）	No	1	Total capacity of 270 passenger, 5 doors and 25m long vehicle
3	Multi Bus Bay	Yes	2	
4	Bus Ordering	No	3～6	Platoon of 6 buses

3.4 Arrangement of Variable Factors and Performance Measure

As pointed out previously, bus capacity depends on the speed of acceleration and deceleration of the vehicle, dwell time at station and delay at intersections. In order to understand the limits of bus capacity under various methods of operation in this research, having first assigned a bus service frequency and taken into account the effects of dwell time at station and signals, the average travel speed and lost time over the section that is targeted for evaluation are calculated by tiss-NET.

3.4.1 Variable Factor

Table 4 shows the method of establishing variable factors (conditions for calculation) for simulation.

1) Frequency of Bus Operations
Six patterns of postulated bus service frequencies (number of services per hour per direction) are set over a range of 60 to 360 buses per hour.

2) Dwell Time at Station
Because peak hour capacity is being assumed for this analysis, it is presumed that there will be no variance in demand on each route of an hour. Therefore, dwell time at station is taken to be common to all buses and all stations and, having established the average values shown in Table 4, the variance is set at 0.1 across the board.

3) Green Time Ratio (g/C)
At intermediate intersections, two patterns, 1.0 and 0.5, are taken for the green time ratio in the direction straight ahead. A green time ratio of 1.0 generally indicates that 100% of the signal cycle length is allocated to the green signal in the straight ahead direction but here, as a case in which absolutely no lost time is generated at an intersection due to priority signal control, it is decided to replace it with a green time ratio of 1.0.

Table 4. Variable Factor

Variable Factor	Measure	Preset Value
Bus Frequency	bus/h/d	60, 90, 120, 150, 180, 360 (6 Cases)
Average Dwell time	sec/station	10, 20, 30, 40, 50, 60 (6 Cases) （Variance are set up 0.1 uniformly）
Green Time Ratio (g/C)	—	1.0, 0.5 (2 Cases)*

NOTE: The ratio of effective green time to total signal cycle length, equals 1.0 for unsignalized streets and bus facilities

3.4.2 Performance Measure

Concerning the stakeholders of bus operation on exclusive busways, apart from passengers and bus operators (bus drivers), and then in a case of a local street being intersected on the level, the effect on other vehicles at signalized intersection must be considered.

For passengers, station waiting time and bus dwell time can be cited as performance measures related to convenience but the former is ignored here on the assumption that there will be high frequency transport at peak hours. Moreover, the latter is evaluated using average speed, which is an average service index.

For bus operators, average speed that shows operation efficiency and time spent at stations and signal-controlled intersections waiting for the leading bus to start (lost time) due to high frequency service are evaluated.

Bus priority signal control affects other vehicles traveling on a cross street. In addition, the effect along the roadside includes problems such as noise, emissions and vibration. These will increase in proportion to the increase of bus services, there are omitted for simplicity in this paper.

From the above, Table 5 sets out each stakeholders in this analysis, as well as the performance measure and the viewpoint of evaluation. In addition, since more frequent service causes lower avg. speed, bus frequency is put in as exogenous variable in order to perform sensitivity analysis

Table 5. Performance Measure

<table>
<tr><th>Stakeholders</th><th>Performance Measures</th><th>Viewpoint for Evaluation</th></tr>
<tr><td>Passenger</td><td rowspan="2">Average Speed</td><td>To Evaluate the measure as effects on passenger convenience due to alternatives of bus operation and variable factors</td></tr>
<tr><td rowspan="2">Bus operator (Driver)</td><td>To Evaluate the measure as efficiency and service level of bus operator</td></tr>
<tr><td>Lost Time*</td><td>To Evaluate time spent to wait until bus stop becomes available</td></tr>
</table>

*Lost Time = (avg. speed of all buses – free flow operating speed) / total length

3.5 Consideration and Evaluation of Capacity of Each Bus Operating Method

The authors show the results of calculating performance measures by applying tiss-NET, simulation package, to each alternative on the basis of establishing each of the above types of conditions. Here, we show the average value calculated by 10 times trials respectively.

1) Normal Service
Figure3 shows the results of calculations for a normal service. On looking at average dwell time of 30 seconds, average speed of 20 km/h can be kept with 60buses/h but to operate a service with a frequency higher than that, time is lost in waiting for the lead bus at a station to move off and the average speed is reduced. In particular, at 120buses/h the authors can see that time lost at stations increases sharply when the average dwell time exceeds 30 seconds.

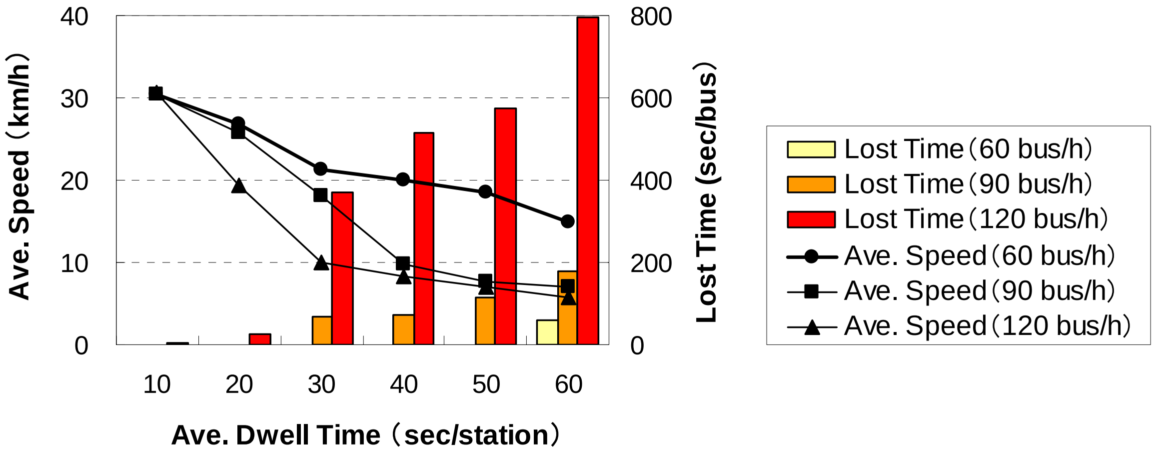


Figure 3. Case 1: Results of Calculation for Normal Service

2) High Capacity Bus Operating Service
High capacity (bi-articulated) buses increase passenger capacity without changing the bus service frequency. Figure 4 shows the results of comparing bi-articulated bus operation of 60buses/h with Case1. For the same service frequency, the average speed is a little less because the bi-articulated buses are twice as long as conventional buses but they can ensure three times the passenger carrying capacity. Conversely, to ensure the same passenger capacity as the bi-articulated buses with conventional buses would require more than twice the service frequency and the authors can see that the average speed would be significantly reduced.

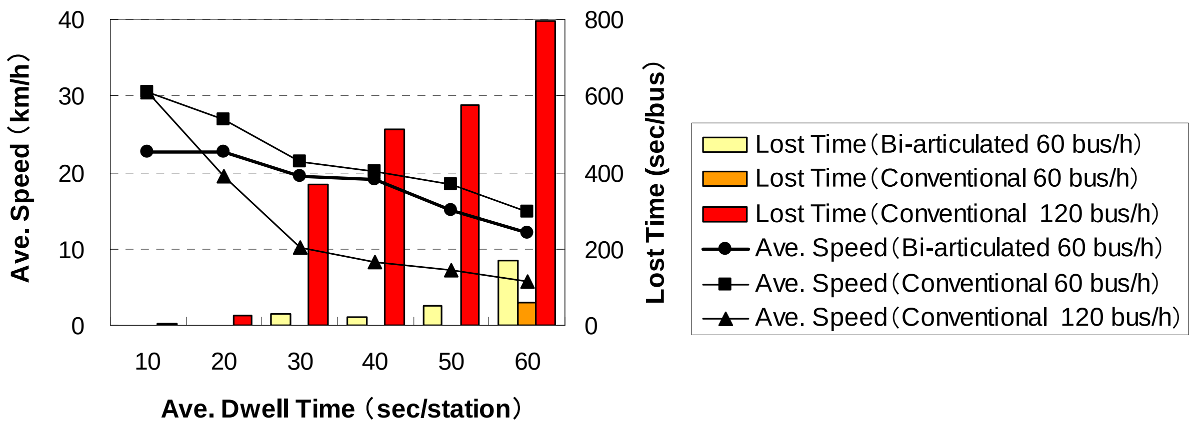


Figure 4. Case 2: Comparing Result of High Capacity Bus Operating to Case1

3) Operation with Multi-Bus Bays for Several Buses

As shown in Figure 5, by establishing several bus bays where several buses can stop at a station at the same time, even bus transit with a frequency as high as 120 or more buses/h can keep average speed of 20 km/h if the average dwell time is about 30 seconds. However, for this analysis, without setting too high a variance for dwell times of individual buses, it is necessary to take into account the case of no passengers boarding or alighting at a station (dwell time approximately zero). Moreover, in the results of references up to now, it has been shown that the increase in the number of bus bays at a station is not proportional to bus capacity and this must be noted in actual planning.

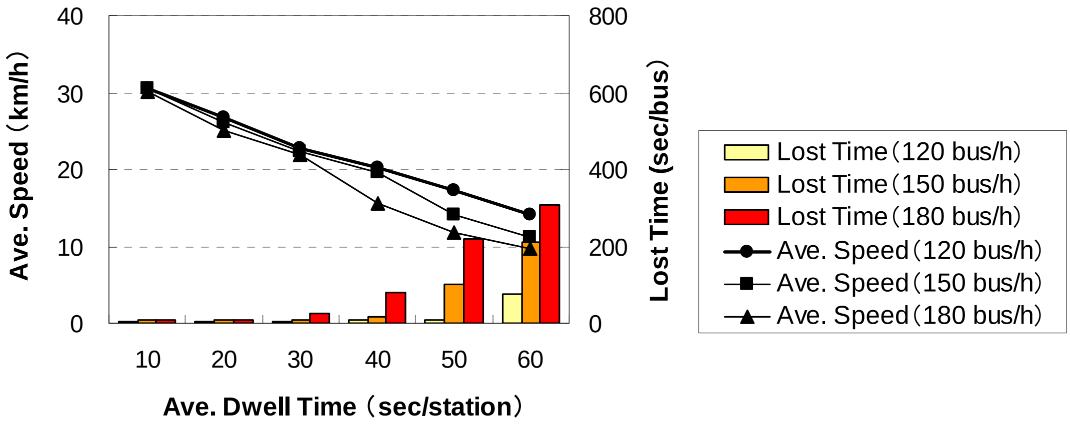


Figure 5. Case 3: Results of Calculation for Operation with Multi-Bus Bays

4) Operation Bus Ordering System

Here, as previously learned from the example of bus ordering at Porto Alegre, Brazil, transport with a convoy system at the high frequency of 360 buses per hour was reproduced for a trial calculation of the limiting value of bus transit. From this result it was found that average speed of 20 km/h can be kept if bus priority signal control (g/C=1.0) is set as a precondition and station dwell time is no more than 40 seconds. If priority signal control is not set (g/C=0.5) and station dwell time is no more than 30 seconds, although the speed is reduced by about 20 to 30 percent compared with the case in which priority signal control is set, this suggested that using bus convoy system could enable very high frequency bus transit to be applied without slow down.

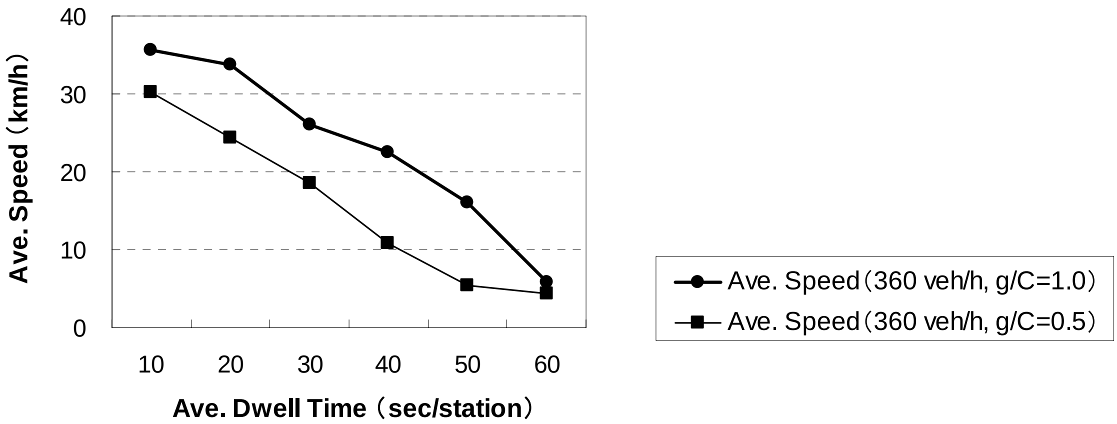


Figure 6. Case 4 : Results of Calculation for Bus Ordering System*

*6 Bus convoy system by signal control, Capacity = 360 buses/h

3.6 Result of Calculation

In this chapter, after establishing the conditions for calculating alternatives with exclusive busway, the authors calculated the relationship between bus transit frequency, average speed and lost time by microscopic simulation.

These results show the average speeds for each case when station dwell time is 30 seconds and the green time ratio g/C = 0.5 for example and can be arranged as in Table 6. Taking a service level with average speed of 20 km/h as a temporary criterion, in a normal operation (Case 1) the same level cannot be kept when the transit frequency exceeds 90 buses/h but by proceeding to operate with multi-bus bays (Case 3) it becomes possible to operate at the same level with 180 buses per hour per direction. Moreover, if the authors look at passenger capacity, because high capacity buses (Case 2) have about three times the seating capacity of conventional buses, with 60 buses per hour per direction they can achieve the equivalent passenger carrying capacity of 180 conventional buses at the same level (average speed of 20 km/h). By convoy system (Case 4) at the high frequency of 360 buses per hour per direction, although the service level is decreased (18.5 km/h), when converted to passenger capacity, a capacity of 28,800 persons per hour is achieved, which is thought to indicate the limiting value of bus transit capacity.

The realization of a high frequency for bus transit services requires the consideration of infrastructure development costs such as stations that are able to accommodate several buses stopping at the same time and operating costs such increased numbers of drivers. Therefore, it is important to clarify areas of application from the relationship between capacity and cost by performing a comparative analysis of bus transit systems and other transit systems.

Table 6. Comparison the Average Speed for Each Case

Frequency (bus/h/d)	Case1 Normal service	Case2 High-Capacity (bi-articulated)	Case3 Multi-Bus Bay	Case4 Bus Ordering
60	21.4	20.1	-	-
90	18.1	-	-	-
120	10.1	-	22.8	-
150	-	-	22.4	-
180	-	-	21.8	-
360	-	-	-	18.5

Note:
Average Dwell Time＝30sec， g/C＝0.5
In case2, passenger capacity is three times conventional bus because of using 270-passenger bi-articulated bus. (The capacity of bus except Case2 is 80-passenger)

4. ANALYSIS OF BUS TRANSIT APPLICATION DOMAINS AREAS – RELATIONSHIP OF COST TO CAPACITY

The previous chapter showed simply that high frequency bus transit can be realized by devising methods of using bus stopping systems and stations on an exclusive right-of-way while maintaining comparatively high service levels. Next, by comparative analysis with alternative transit systems on the basis of the relationship of capacity with the costs involved in operating high frequency bus transit, the authors show domain areas of application for bus transit.

4.1 Approaches to Analysis

Up to now a number of research studies have been carried on the basis of detailed items related to models of public transport costs. Here, having established simple preconditions and with fixed spatial conditions, the relationship between capacity and system costs are calculated.

At the stage of planning alternatives for the planned introduction of a specific transit system in an actual city, the necessary space and the cost of the land required must be considered on the basis of the planning conditions and the system characteristics. However, since this research is positioned at the stage of basic research on evaluating the possibility of applying bus transit with exclusive right-of-way, having assumed that the land needed for the development will have been secured beforehand; it was decided to compare the costs of each transit system on the same basis. In this analysis the cost of land will not be included in the initial costs but because the necessary space such as space for roads and stations is different for each transit system, if land costs were to be considered, it can be assumed that it would impact on the capacity-cost relationship. Therefore, this will be noted as an item to be added in future for a more detailed analysis that assumes a realistic situation.

4.2 Establishment of Preconditions

Analysis preconditions were established as follows:

- A route 10 km long with 11 stations at 1 km intervals is assumed
- All transport systems can be developed under the system
- Assume that demand will be developed uniformly along the route and all passengers will get on at the nearest station and travel to the terminus (many to one)
- The space immediately in front of the terminus station is the point of maximum transport
- Infrastructure and system parts (including roads and station structures, overhead facilities and vehicles other than buses) to be depreciated over 50 year, buses to be depreciated over 5 years, costs to be calculated per year (social discount rate to be 4%)

4.3 Establishment of Alternative Transit Systems

Various elements of alternative transit systems were determined as in Tables 7 and 8. Average values based on Japan’s existing statistical data are used for the various elements of each transport system and it can be said that they have been established appropriately after debate on relative relationships.

Table 7. Establishment of Elements of Alternative Transit Systems

Alternatives	Elements	Vehicle per Unit	Capacity	Average Speed (Donne)	Initial Cost (Included Car)	
	Measure	(veh/unit)	(passenger /veh)	(km/h)	(billion yen/km)	
Subway		5	150	32	27.5	
AGT		3	100	27	11.5	
Monorail		4	75	30	10.5	
LRT		2	150	25	5.0	
Busway	Conventional Bus	1	80	20	1.0	*20**
	Bi-articulated Bus	1	270			*50**
	Bus Ordering	6	80			*20**

*In case of bus, costs of vehicles are set up separately. （Measure: million yen/vehicle）
Source: Data collected in Japan (2003)

Table 8. Operating Cost of Transit system Alternatives

Specification	Measure	Subway	AGT	Monorail	LRT
Rail Track Maintenance	yen /car-km	56.0	30.3	45.1	40.0
Cable Way Maintenance	yen / car-km	39.3	35.5	66.2	23.2
Vehicle Maintenance	yen / car-km	39.8	61.3	36.0	60.0
Operation	1,000 yen /person	353	283	381	126
Transportation	1,000 yen/station	64,043	38,166	19,112	3,472
Power Cost	yen / car-km	35.10	19.30	57.04	39.00
General Administration	1,000 yen /person	11,688	11,800	8,533	2,752

Source: Data collected in Japan (2003)

4.4 Results of analysis and considerations

Results of analysis are shown in Figure 7. As a result of calculations, if the peak hour demand is about 10,000 passengers per hour, the system by bi-articulated buses with 270-passenger is the most cost-efficient system. And the bus convoy service also would be more advantageous than other transit systems save and except bi-articulated buses but in this case station facilities capable of handling six buses at once must be developed. If an attempt were to be made to transport 20,000 or more passengers per hour with the same system its superiority over AGT would be lost because of the increased numbers of crew members and the rise in personal expense. Due to technical developments, however, (crewless convoys for instance) it may be possible to suppress the rise in personal expense.

Moreover, under the conditions of this analysis, light rail transit (LRT) which is thought to be the closest alternative system to bus transit in the matter of level traveling space, is less expensive than other rail based linehaul transit systems and in the region of transport demand of 5,000 or more passengers per hour it would be more cost-advantageous than any bus transit other than bi-articulated buses. However, in actual use exclusive busways and LRT must be assured of level running space and it must also be noted at the actual planning stage that this relationship will change if land acquisition cost is taken into account.

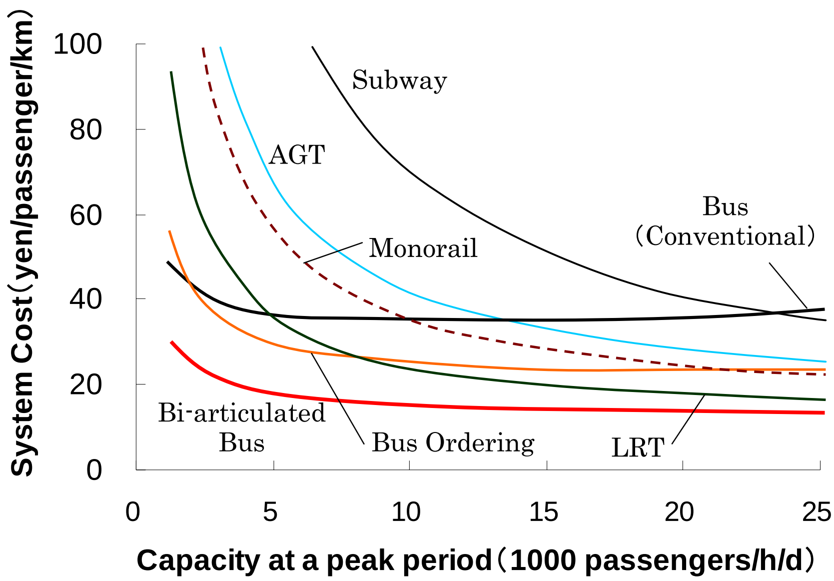


Figure 7. Relationship between Capacity at peak period and System Cost

5. REQUIREMENTS OF INTRODUCTION BRT IN ASIAN CITY

Chapter 3 and Chapter 4 showed the capacity and domain areas of application of BRT with various preconditions for Japan based on the BRT that was applied in Brazil. However, as already shown in Chapter 1, it is not advisable for the results of these analyses and the manual for introducing BRT in the United States to be applied in Asian cities just as they are. This is because American and Japanese cities are already mature and unlikely to experience great population increase or economic development in the future, whereas tremendous economic development in the major Asian cities (especially in Southeast Asian countries) can be predicted in the near future. Population growth and increased income are expediting the use of motor vehicles and with the unreliability of economic activities, the various risks involved in infrastructure development such as urban transport utilities are thought to be increasing. As many cities in developed countries have already discovered, once people have had the personal experience of using an automobile it is not easy to convert them to using public transport that will be developed afterwards. Increase of car user might lead the problems such as that the decline of shopping function in downtown and increase of car oriented shopping facilities in the suburban areas with lower land prices in turn those problems promote further increase car usage, which has been already well-known social problems in developed countries. In order to overcome this vicious circle, it is essential to put the public transport network on a firm footing as the foundation of the city before the sudden increase in motor vehicle traffic, to obtain an appreciation that using public transport is more convenient than using a car and then to maintain the attraction of the city center.

As shown in many development manuals, BRT can be developed for a cost that is from a tenth to a fiftieth of a rail based linehaul transit system. In short, that means that the financial resources to develop one kilometer of a rail based linehaul transit system could be used to develop between ten and fifty kilometers of BRT. Considering the increasing demand for cars in Asian cities from now on, it is important to develop public transport networks as quickly as possible and BRT will probably play a major role after the integration of land usage planning with transport policy.

6. CONCLUSIONS

In this paper, the authors focused on the possibility of improving the capacity of exclusive busway on which several alternatives have been established and evaluated their capacity in order to evaluate the feasibility of applying bus rapid transit (BRT) with exclusive right-of-way. In addition, the authors analyzed domain areas for the application of bus transit systems especially from the cost point pf view.
The results of this paper are the following three points:

1) That improvement of operations at bus stations could enhance frequent bus transport keeping a certain level of service
2) That bus transit system could carry more than 10,000 passengers per hour just with some operational improvements.
3) It is meaningful to consider BRT system as policy alternatives in largest Asian cities.

In this paper, since there were no examples of BRT with exclusive busway according to the plan and it was difficult to obtain actual operating data in Japan, we have calculated and estimated within the limits of hypothetical conditions. Therefore, the evaluations of BRT by existing data must be continued to include the estimation of other evaluation indicators while the set conditions are carefully examined.

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